New Hydrological Approach for Environmental Protection and Floods Management

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Abstract. Sustainable development means to protect and improve environment for future generation use. An effective protection requires action to limit global warming prevention catastrophic phenomena, such as severe floods or long-term droughts, and safeguarding people from their effects. Analyzing these phenomena evolution, the Romanian specialized institutes have adopted a new approach and developed a modern strategy, based on the latest hydrological theory available worldwide. According to this strategy, the Romanian authorities have begun to develop and implement new norms and technical regulations. These norms and technical regulations have fully changed the previous approach of the storm and runoff modelling in Romania. The paper presents the modeling methods of the design storm and overland runoff, which have been the base of the new norms and regulations (Romanian Standard SR 1846-2/2006, “National medium and long-term flood risk management strategy”, “Methodology for the establishment of the hydrographic basins exposed to floods”) and points out their implications in the environmental protection, water management field and in the fight against extreme meteorological phenomena such as severe floods and droughts.

Keywords: environmental protection, design storm, overland runoff, flood risk management, drainage facilities.

INTRODUCTION

Water represents the life foundation and plays a very important role for the agriculture and rural sustainable development. Unfortunately, because of the climate changes and intensive human activities such as intense deforestation and excessive land exploitation, catastrophic phenomena (floods and long-term droughts) occurred during last decade. All these events had a negative impact on environment, on the agricultural production and on rural development in Romania.

Analyzing these phenomena evolution, the Romanian specialized institutes have adopted a new approach and developed a modern strategy, based on the latest hydrological theory available worldwide. Relaying on this strategy, the Romanian authorities have started to develop and implement new norms and technical regulations. These norms and technical regulations have changed the previous approach of the storm and runoff modeling in our country.

MATERIALS AND METHODS

In order to face extreme meteorological events like tornados and floods and prevent their effects on environment and population, it is necessary to be able to model these phenomena, study their effects and adopt an adequate designs and hydraulic structures and water management. Dimensioning the drainage facilities implies to model as good as possible
the design storm (the flood hydrograph associated with a return period), in correlation with the overland runoff. The following methods are frequently used to define the design storm:

1) Design storm derived from the IDF curves;
2) Design storm derived from observed rainfalls
3) Design storm derived from historical outstanding rainfalls;
4) Space-temporal analysis of the 24-hour design storm (Diaconu method).

1) Design storm derived from the IDF curves:
   - Uniform time distribution rainfall is characterized by a constant intensity over its duration, which is equal to the time of concentration of the basin for small areas. The constant time distribution of the assumed design storm intensity leads to an underestimation of the design peak discharge, particularly for basin areas greater than 10 km² (Drobot and Serban, 1999).
   - Composite storm concept is closer to reality than the uniform storm and its occurrence is based on an Intensity-Duration-Frequency curve as well. The basic hypothesis of the composite storm is that the maximum intensities that are averaged over certain duration are the same with those obtained from the IDF curves (Fig. 1).

![Fig. 1 Construction of the composite storm](image)

The total duration of the design storm and the mean intensity storm are determined for a certain probability to exceed the frequency and rainfall duration corresponding to the concentration time of the basin. The total duration is shared into partial time intervals with a constant time step and the average intensity is assessed for all cumulated duration values. The rainfall depths and rain intensity for each time step are determined as the difference between the values of two subsequent cumulated storm depths corresponding to each time interval. The decreasing graph of the intensity might be "re-arranged" as shown in Fig. 2.

![Fig. 2 Design storm base on the composite storm method](image)
- Method of critical sequence of rainfall (Stanescu, 1995) is defined by a progressive increase in the rainfall intensity over four days, in such a manner that, at the start of the flood triggering storm the soil would be in a state of significant humidity. Such a time distribution of rainfall results in a maximization of the flood volume and peak discharge as the triggering storm would fall on a wet soil and hence the infiltration loses would be small. This method developed by the US Office of the Chief of Engineers takes into consideration the assumption of a 4 day-duration rainfall participating to the flood formation. For several standard estimates of the rainfall duration and a certain return period T, depths of rainfall are determined using IDF curves. Standard values of duration are 1, 2, 3, 4, 5, 6, 12, 18, 24, 48, 72 and 96 hours (4 days).

- Design storm "Chicago type" (Keifer and Chu, 1957)- the synthetic hyetograph is based on the parameters of an assumed Intensity-Duration-Frequency relationship. A rainfall distribution (with respect to time) such as that shown by the dashed curve of Fig. 3, i.e. with a maximum intensity $i_{\text{max}}$ at the start of rainfall at $t=0$, which then decreases monotonically with elapsed time $t$, according to some function $f(t)$ which is, as yet, unknown.

![Fig. 3 Development of the “Chicago” storm](image)

If the duration of such a storm is $t_d$ then it is easy to see that the total volume of rainfall is represented by the area under the curve from $t=0$ to $t=t_d$. The average rainfall intensity for such an event could be estimated as $i_{\text{ave}} = \frac{\text{Volume}}{t_d}$ as illustrated by the shaded rectangle of Fig. 3. Several storms with different durations $t_d$ but with the same time distribution of intensity would produce values of $i_{\text{ave}}$ which decrease as $t_d$ increases, leading to the dotted curve of Fig. 3.

$$i_{\text{ave}} = \frac{\text{Volume}}{t_d} = \frac{1}{t_d} \int_0^{t_d} f(t)dt$$

Calculation of the discretized rainfall hyetograph is carried out by integrating the equation [1] to obtain a curve of accumulated volume. For convenience this curve is computed so that volume $V$ is zero at $t=tp$ and is defined in terms of the elapsed time after and before $tp$. 

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2) Design storm derived from observed rainfalls

This category of methods is based on the concept of deriving the design storm from the cumulative curve of the rainfall depth as a function of time. As these curves are non-dimensional they are used for any value of the total depth and duration of a design storm.

- SCS method for deriving the 24-hours design storm – the method developed by US-Soil Conservation Service (SCS) in 1986 assesses the design storm aiming to determine the design flood of rural catchments. For the USA territory, 4 types of cumulative curves, have been obtained. The 24 hours total precipitation determined from IDF curves for a given return period (T years) is distributed in terms of frequency over a time interval as the derivative of the cumulative curve (Fig. 4). Huff proposed a series of cumulative curves of depths of rainfalls of several duration values comprised between 3-48 hours. The rainfalls were grouped into four families (four quartiles) in compliance with the period during which the maximum storm occurs. On the other hand, for each quartile the probability of occurrence of different time distribution has been assessed.

- Design storm derived as dimensionless average cumulative depth (the method of integrated curve) consists in:
  - selecting the observed storms (n storms) having comparable characteristics concerning the total depth and duration with the design storm;
  - expressing the time steps of each storm as percentage of this total duration;
  - expressing the depth of rainfall in each time step as a percentage of the total depth;
  - and computing the average percentage of depth for each time step.

For certain duration the design storm depth derived from IDF curves is then multiplied with percentages.
3) Design storm derived from historical outstanding rainfalls hydraulic structures based on values recorded for extreme events. Two concepts have to be considered for using outstanding rainfalls as design storms:
- the observed rainfall should have similar return periods with the design storm that may be used to derive the design flood;
- a cumulative non-dimensional curve might be derived from the observed rainfall data and then one can determine the design hyetograph from the depth of rainfall with a certain return period that is distributed according to the integral curve. However, the total duration of the design storm should be of the same order of magnitude as the observed rainfall.

4) Spatial-temporal analysis of the 24-hour design storm (Diaconu method)
In each method described above, the rainstorm event is considered at one point. The "punctual event simulation" procedures might be applied for small size basins. As the runoff is a result of an integration of the total quantity of rainfall across the basin, for larger basin areas the average value of the rain event has to be considered. The spatial-temporal analysis can solve the problem, named the rainfall averaged over the larger size basin areas giving a better estimation of the quartiles (frequencies) of the rainfall depth (or intensity). To illustrate the spatio-temporal method of Diaconu (Diaconu, C. 1988), the 24 hour-rainfall data at 19 stations located in the southern part of Romania, across an area of 10000 km\(^2\), were considered. The stations were grouped according to the length of the record period. Analyzing the recorded data, it can be observed that for all categories there is a significant variation of the maximum recorded value of rainfall. On the basis of annual maximum estimations of the 24-hour rainfalls, Diaconu derived the "temporal" quartiles of 2%-90% for 50 stations in an area of 10000 km\(^2\) (Diaconu, C., Serban, P. 1994). A series of 50 temporal quartiles is formed from values obtained at each station. Then, a "spatial probability curve" for a given temporal quartile is drawn. Using all the rows of 50 items for the temporal quartiles, the estimate of the 24-hour maximum rainfall \(X_{p_T\cap p_S}\) of a certain probability in terms of time \(T\) and in space \(S\) is determined.

![Variation of \(X_{p_T\cap p_S}\) function for combined probabilities](image)

The curves in Fig. 5 allow determining the risk that a certain value would be exceeded in a given return period. An important problem is the manner in which the spatial probability
reflects the areas expressed in a quantitative form. For the 24 hour-precipitation across an area of \( F_z \text{ km}^2 \), a percentage \( p_S(\%) \) is assimilated with an area \( F_{basin} \) equal to the same percentage from the total area, as follows:

\[
F_{basin} = p_S(\%) \cdot F_z
\]

It is obvious that for the same spatial-temporal curve of combined probabilities and for the same estimate of spatial probability the area of the basin varies with \( F_z \). Based on this theory, Diaconu drawn the graph in Fig. 6. According to the shape of the curves from this Fig. I can see that either for the temporal probability \( p_T(\%) \) equal to 0.01% or 5% the curves have an asymptotically trend in the zone comprised between 40000-80000 km\(^2\). Across the analysed area, the 24 hour-rainfall of 10000 years return period over an area of 10 km\(^2\) tends to 500 mm. The rainfall of a return period equal to 20 years over an area of 100 km\(^2\) tends to 170 mm.

![Graph](image)

**Fig. 6 Relationship between the temporal and probability \( p_T(\%) \)**

**RESULTS AND DISCUSSION**

The Romanian authorities have developed and implement new norms and technical regulations such as Romanian Standard SR 1846-2/2006 “Design regulations for drainage systems – Computation of the rainfall flows”, “National medium and long-term flood risk management strategy”, and “Methodology for the establishment of the hydrographic basins exposed to floods”, based on the above presented theory and taking into consideration the extreme phenomena occurred in the last decade. These norms and technical regulations have changed the previous approach on the storm and runoff modeling in Romania.

Romanian Standard SR 1846-2/2006 - “Design regulations for drainage systems – Computation of the rainfall flows” stipulates the following methods for the determination of the average intensity of design storm for drainage system:

- the use of IDF curves and the standard frequencies for storm duration of 5…1440 minutes for areas smaller or equal to 10 km\(^2\). Romania has 19 different areas, areas for which the rainfall is assumed to be identical (Drobot and Serban, 1999);
- the use of the spatial-temporal analysis of the 24-hour design storm (Diaconu, C. 1988), for areas between 10 km\(^2\) and 50 km\(^2\). In order to know the real rainfall distribution in
time, even in case of the application of the rational methods (when the uniform distribution can lead to underestimation of the maximum rainfall flow), the hyetograph of the rainfall is necessary. The design storm distribution can be drawn base on the composite storm method, or based on “Design storm derived as dimensionless average cumulative depth (the method of integrated curve)”, when there are measurements of at least 20 maximum rainfalls;

- for areas larger than 50 km$^2$, it is recommended to split the area into subcatchments, having 50 km$^2$ maximum, and adopt the spatial-temporal analysis of the 24-hour design storm, for each of them.

Methodology for the establishment of the hydrographic basins exposed to floods has as goal the identification of the small basins where high floods can occur. The methodology provides the three steps to follow:

- preliminary sort of the basins;
- diagnose using simplified methods;
- detailed diagnose using mathematical modeling for the basins where the flood consequences are considered important.

The preliminary sort of the basins is made using:

- the Runoff coefficient method (Mita, P., 1996, INMH 1997). The basins are sorted by the aid of the map with zones where the maximum hourly rainfall exceeds the probability of 1% and the map with the corresponding global runoff coefficient;
- the physical graphical method. This method is based on Curve Number index in SCS model for 24-hours design storm, and, for a given catchment, the potential storage capacity and the lag time are computed (Chendes, V., 2007).

The diagnose using simplified methods is used for the basins selected after the preliminary sort and refers to:

- the estimation method of the rainfall weir (Oprisan, E., 2006);
- the genetic method based on the selection of the rainfall capable to generate extreme floods and computing the runoff coefficient of the catchment, using SCS model.

The detailed diagnose using mathematical modeling is not mandatory, but it is recommended to be used when the flood consequences are considered important. The following steps should be followed:

- the features of the storm generating high floods are established based on the probability to exceed the design storm of 5%, 2%, 1% and 0.5% and for a duration of 30 minutes, 1 hour, 2 hours and 3 hours;
- for the above settled storms, the rainfall depth (using the spatial – temporal analysis for probabilities of exceeding the design storm) and the rainfall hyetograph are obtained (using the model of “Design storm derived as dimensionless average cumulative depth method - the method of integrated curve); a mathematical modeling and software application (Butts, M.B et al, 2005);
- computation of the flood spreading downstream are performed to estimate the catchment response, using Potop or Mike She models;
- calculation of the flood spreading are performed for downstream area of the catchement,
- characterization of the flooding areas and damages estimations are made for the identified areas.
CONCLUSIONS

Extreme meteorological events like tornados and floods, as result of global warming have affected frequently Romania in the last years. In order to face them and prevent their effects, the Romanian authorities have developed and implemented new norms and technical regulations such as:

- “National medium and long-term flood risk management strategy”;
- “Methodology for the establishment of the hydrographic basins exposed to floods”.
- These norms and technical regulations have adopted the modern hydrological approach of the storm and runoff modeling in Romania.

REFERENCES

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